REVIEW RESOURCES

Lesson 17: The Systems Engineering Process

IPPD: Satisfying User Requirements

The Integrated Product and Process Development (IPPD) approach includes business, managerial, and technical components. These components work in an integrated manner to ensure that an optimally balanced system is evolved that meets the user's operational requirements.

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Systems Engineering Overview

As the technical component of IPPD, Systems Engineering:

- Transforms operational needs and requirements into an integrated system design solution through concurrent consideration of all life-cycle needs (i.e., development, manufacturing, test and evaluation, verification, deployment, operations, support, training, and disposal).
- Ensures the compatibility, interoperability, and integration of all functional and physical interfaces, and ensures that the system definition and design reflect the requirements for all system elements: hardware, software, facilities, people, and data.
- Characterizes and manages technical risks.

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Systems Engineering: Maintaining a Balance

Systems Engineering manages risk by establishing and maintaining a proper balance between the system solution and factors that directly impact that solution. These factors include:

- Performance
- Cost
- Schedule

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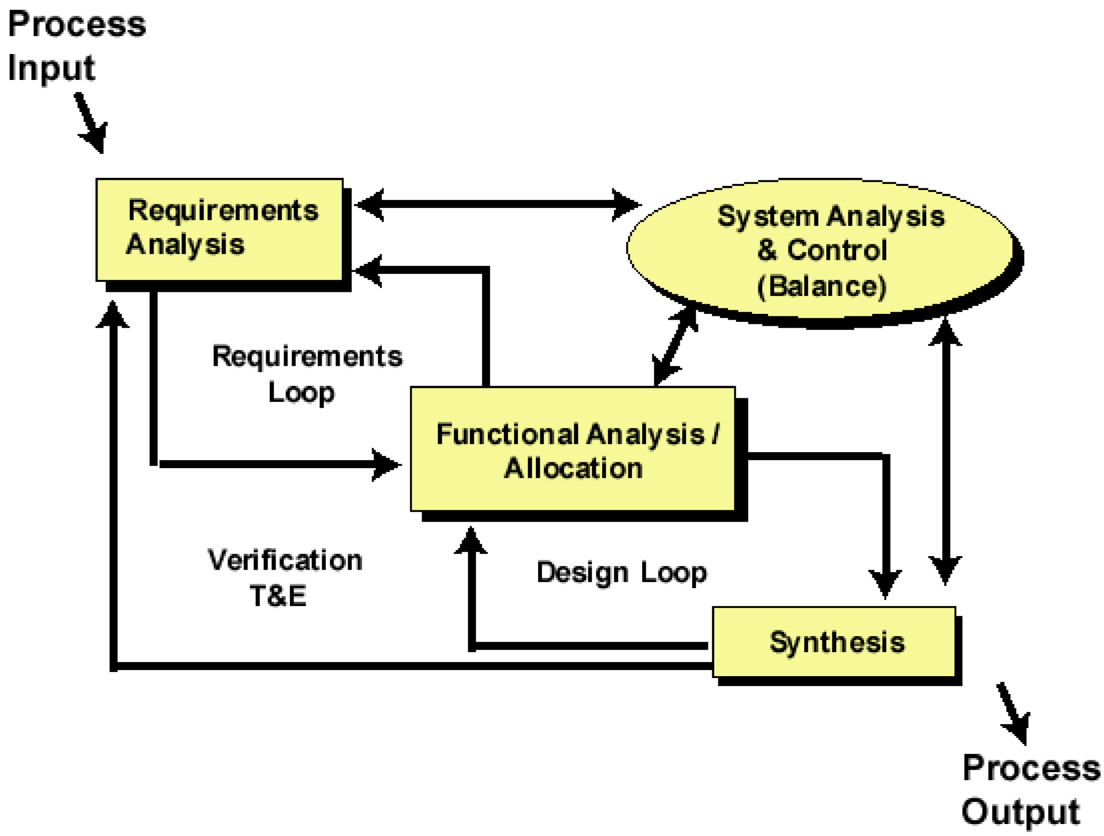
The Systems Engineering Process (SEP)

The Systems Engineering Process (SEP):

- Is a problem-solving process.
- Is iterative in nature (repeats steps).
- Translates the user's need into design criteria, and eventually into designs for new or improved systems.
- Ensures an integrated approach by orchestrating the activities of various technical disciplines.

The Systems Engineering Process Mandated by DOD 5000.2-R



Process Input

Inputs can be user requirements, new technology, results from a previous program phase, environmental constraints, and/or anything else that defines constraints or requirements of the program.

Requirements Analysis

Requirements Analysis is the process of establishing and refining system performance thresholds and objectives (e.g., what must be done, by whom, and how well), as well as any system performance constraints (e.g., environmental, size, weight).

A good Requirements Analysis will:

- Define the system mission.
- Define customer/user needs.
- Define operations & support concepts.
- Define how requirements are to be verified.

Throughout the acquisition process, the program office shall work with the user to establish and refine operational and design requirements that result in the proper balance between performance and cost within affordability constraints.

Requirements analysis shall be conducted interactively with functional analysis/allocation to develop and refine system-level functional and performance requirements and external interfaces, and provide traceability among user requirements and design requirements. (Source: DOD 5000.2-R (Para 4.3))

Functional Analysis/Allocation

The Functional Analysis/Allocation step determines and documents all functions the system must perform (e.g., fly, land, carry, detect). These functions are decomposed to the lowest levels necessary to define the subsystems needed to form the complete system.

Functional Analysis/Allocation shall be performed interactively to define successfully lower level functional performance requirements, including functional interfaces and architecture.

Functional and performance requirements shall be traceable to higher level requirements. System requirements shall be allocated and defined in sufficient detail to provide design and verification criteria to support the integrated system design. (Source: DOD 5000.2-R (Para 4.3))

Synthesis

The Synthesis step (referred to as Design Synthesis and Verification) defines the physical architecture, and designs the system to achieve the functions and subfunctions identified in the Functional Analysis/Allocation step.

Synthesis is part of the following loops:

- Design Loop: Using the design loop, the evolving design is compared iteratively to the system functions to ensure that each can be performed and supported.
- Verification Loop: Using the verification loop, testing and other methods are implemented to ensure that the design meets user operational needs originally identified in Requirements Analysis.

Design Synthesis and Verification

Design Synthesis and Verification activities shall translate functional and performance requirements into design solutions to include:

- Alternative people, product, and process concepts and solutions.
- Internal and external interfaces. These design solutions shall be in sufficient detail to verify requirements have been met.

The verification of the design shall include a cost-effective combination of design analysis, design modeling and simulation, and demonstration and testing. The verification process shall address the design tools, products, and processes. (Source: DOD 5000.2-R (Para 4.3))

System Analysis and Control

System Analysis and Control provides the tools within the Systems Engineering Process to manage risk and to control and gain insight into the design, development, testing, support, quality assurance, and manufacturing processes.

Process Output

The output of SEP is not the system itself; it is, rather, the integrated solution to the user requirements. The actual outputs will be (depending on phase):

- System and item specifications.
- Drawings.
- A technical database that contains the data used to develop the design (e.g., trade studies, risk plans, technical performance measures, test plans and reports).

This information provides a basis that can be used to further develop the design or as a basis for further decisions.

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Government and Contractor Roles

The Government and Contractor roles in the SEP are summarized below.

Government	• Ensures that the contractor has responsible design, testing, and manufacturing proceses. • Identifies and manage technical risks. • Verifies that technical solutions satisfy customer requirements.
Contractor	• Uses SEP in planning, designing, and internally testing the system and its required support components.

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SEP Outputs

Specifications Functions

Specifications ensure that the fielded system meets the user requirements and conforms with other process inputs. Specifications perform two broad functions in the Systems Engineering Process:

1. Specifications act as program constraints (inputs).
   Examples:
   - Detail specifications (Industry and Military).
   - Performance specifications (Industry and Military).
   - Interface specifications.
2. Specifications describe product configuration baselines.
   Example:
   - Program-unique specifications.

Performance-Based Specifications and Standards

Programs should document the system design by:

- Using performance-based specifications as preferred standards.
- Choosing specifications and standards adopted by industry.
- Requiring control of interfaces between the elements of the system.
- Encouraging alternative solutions by contractors.

Detailed specifications and standards are no longer routinely imposed on the contractor by the

Government.

Program-Unique Specifications

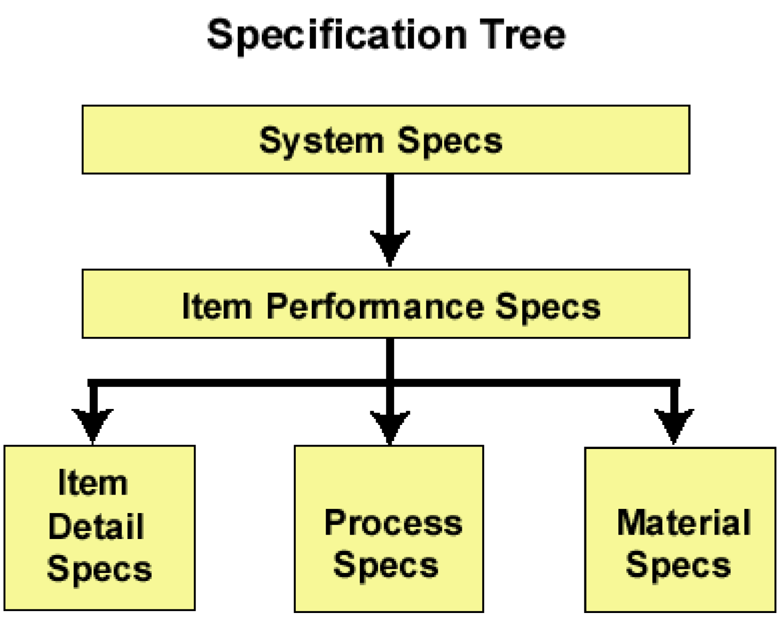
In general, a program-unique specification describes a product or a system. There are several types of program-unique specifications encountered in DOD programs:

- System Specifications.
- Item Performance Specifications.
- Item Detail Specifications.
- Process Specifications.
- Material Specifications.

These specifications are derived from all the previous steps and become the SEP outputs.

Specification Development

Specification development is a top-down process that occurs throughout the entire acquisition process. This process begins by identifying the System Specifications, followed by the Item Performance Specifications. Next, the Item Detail, Process, and Material Specifications are defined.



System Specifications

The system specifications describe what the entire system must do.

System Specifications:

- Can be thought of as the translation of the Operational Requirements Document (ORD) into technical requirements.
- Contain requirements the system must meet and describe how they will be verified or tested.

Item Specifications

There are two types of Items Specifications:

- Item Performance: Item Performance Specifications describe the performance required of the

major subsystems below the system level (e.g., "design to" requirements).
- Item Detail: Item detail specifications include specific design parameters (e.g., "build to" requirements).

Process and Material Specifications

Process Specifications define processes to be performed during fabrication, such as:

- Welding
- Soldering
- Bonding

Material Specifications define raw materials or semi-fabricated material used in fabrication, such as:

- Copper pipes
- Aluminum wire

Specification Flowdown

Program-unique specifications are developed with increasing levels of detail as the design matures. Details developed at each level "flow down" to lower levels forming the design requirements at that level.

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SEP System Analysis and Control

The System Analysis and Control element involves both Government and contractors equally in:

- Evaluating system effectiveness.
- Balancing cost, schedule, and risk parameters for development.
- Controlling the system configuration as it progresses from a concept to a completed product.

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System Analysis and Control Tools

There are many tools available to manage risk and to control and gain insight into a design:

- Work Breakdown Structure (WBS)
- Trade-Off Studies
- Technical Risk Management
- Technical Performance Measures
- Configuration Management
- Integrated Data Management
- Interface Controls
- Technical Reviews

Work Breakdown Structure (WBS)

The Work Breakdown Structure (WBS) is the basis for communication throughout the acquisition process. A WBS defines a defense system in product terms–hardware, software, services, data, and facilities–and relates them in a family tree that displays the relationships of the product(s) to each other and to the end product.

This product orientation provides a reasonable, consistent framework for defining defense acquisition programs. The WBS captures years of experience in weapon and automated information systems acquisitions, yet allows flexibility to accommodate any new program's needs. (Source: Defense Acquisition Deskbook, 30 Sept 97, Information Structure, WBS, 2.6.2)

Trade-Off Studies

Trade-Off Studies examine alternatives among requirements and designs at the appropriate level of detail to support decision making and lead to a proper balance between performance and cost.

Technical Risk Management

Technical Risk Management identifies and evaluates potential sources of technical risks based on the design and its associated technology conducted throughout the design process. Technology transition planning and criteria are part of the overall risk management effort. (Source: DOD 5000.2-R, Part 4, Section 4.3)

Technical Performance Measures

Technical Performance Measures determine how well the technical development and design are evolving relative to what was planned and relative to meeting system requirements in terms of performance, risk mitigation, producibility, cost, and schedule. Performance measures must be traceable to performance parameters identified by the operational user (i.e., one of the key performance parameters is on track or in trouble).

Configuration Management

Configuration Management ensures the functional and physical characteristics of an item and its documentation are properly developed according to the Systems Engineering Process. There are four basic functions of Configuration Management:

- Identification
- Control
- Audit
- Status Accounting

Each must work together to effectively control the design.

Configuration Identification

Configuration Identification involves:

- Selection of the items to be managed–the Configuration Items.
- Development of documentation (specifications and drawings) and issuance of identifiers, such as:
  - Nomenclature
  - Part number
  - Serial or lot number
  - Specification and drawing number

Configuration Control

Configuration Control of a Configuration Item (CI) involves a systematic change process that begins with the Configuration Baseline. For each required change, the following processes are implemented:

- Creation of a proposal to change the baseline.
- Justification of the need for the change.
- Evaluation of the impact of the change.
- Coordination among the IPT members.
- Approval (or disapproval) by the PM.
- Implementation by the IPT and/or contractor.

Configuration Audit

Configuration audits are conducted to verify that a completed Configuration Item or system and its documentation:

- Agree with each other.
- Are complete and accurate.
- Satisfy program requirements (meet specifications).

There are two recommended types of configuration audits:

- Functional Configuration Audit (FCA):

  The formal examination of functional characteristics that test data for a Configuration Item (CI), prior to acceptance, to verify that the item has achieved the performance specified in its functional or allocated configuration identification.

- Physical Configuration Audit (PCA):

  Physical examination to verify that the configuration item (CI) "as built" conforms to the technical documentation which defines the item. Approval by the Government program office of the CI product specification and satisfactory completion of this audit establishes the product baseline. May be conducted on first full production or first low rate initial production (LRIP) items.

Specific audits will be tailored by each program.

Configuration Status Accounting

Configuration status accounting process is maintained throughout the system life cycle. Status accounting provides current and historical information to:

- Track the configuration of the fielded systems.
- Track proposed and approved changes to the current system configuration.
- Assist in providing the right logistic support for the right configuration.

Integrated Data Management

Integrated Data Management is a system that captures and controls the technical baseline (configuration documentation, technical data, and technical manuals); provides data correlation and traceability among requirements, designs, decisions, rationale, and other related program planning; and establishes a ready reference for the systems engineering effort. (Source: DOD 500.2-R, Part 4, Section 4.3)

Interface Controls

Interface controls ensure that all internal and external interface requirement changes are properly recorded and communicated to all affected configuration items.

Technical Reviews

The Technical Review process demonstrates and confirms completion of required accomplishments and their exit criteria as defined in program planning. Reviews necessary to demonstrate, confirm, and coordinate progress will be incorporated into overall program planning. (Source: DOD 5000.2-R, Part 4, Section 4.3)

Technical reviews are a means of measuring event-based technical progress. Reviews are held at various stages of system design and development to:

- Evaluate progress based on specific, required accomplishments (exit criteria), and
- Determine if the system is maturing sufficiently to warrant proceeding into the next level of development.

Technical reviews are an excellent discretionary means for the program manager to gain insight into the design and development process. These reviews should:

- Be held for a specific purpose and only when the criteria for holding each review has been met.
- Assess SEP outputs to determine design progress and maturity.
- Determine the contractor's readiness to proceed to the next stage.

Government and Contractor Roles

The Government and the contractor have complementary but different responsibilities in the acquisition of defense systems. Therefore, it follows that they each use the System Analysis and Control tools in different ways.

- The Government oversees and gains insight into the SEP through the use of System Analysis and Control tools.
- The contractor uses System Analysis and Control tools to discipline the internal conduct of the SEP, and to facilitate implementation of the SEP by subcontractors.

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SEP and the Life Cycle

SEP Across the Life Cycle

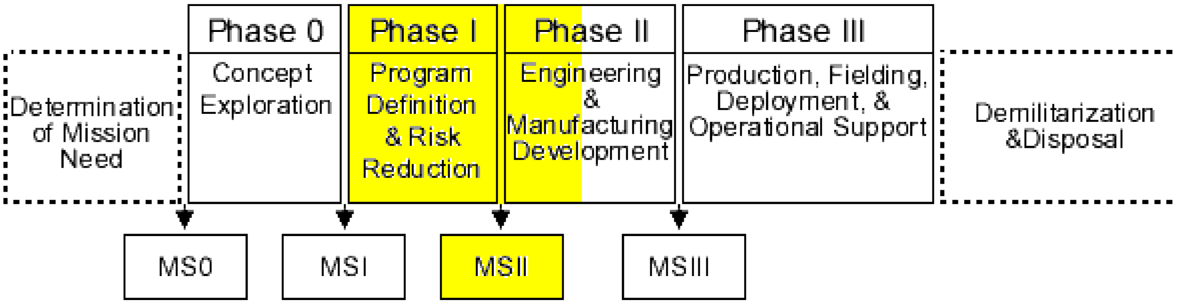
The SEP is a Total System approach to develop a design solution. It is an iterative process that spans all acquisition phases. A concept evolves into a specific system, then necessary subsystems are developed, tested, and integrated into the system. The total system is then tested, manufactured, fielded, supported, and finally disposed of.

System Concept

During Concept Exploration, user needs are translated into design criteria. This translation is documented using the system performance specifications. The system performance specifications (normally controlled by the Government) translate the Operational Requirements Document (ORD) into technical performance requirements that can be used by the contractor to arrive at a system solution.

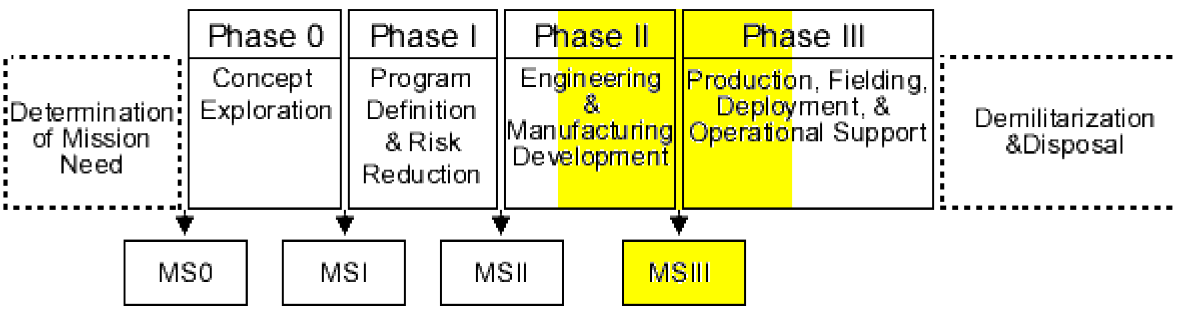
Preliminary Design

System specifications are completed and item performance specifications begin to be developed in the Program Definition and Risk Reduction Phase. Risks are identified and fully explored. Strategies are developed and adapted to reduce and manage risks. Early in Engineering and Manufacturing Development, item performance specifications are completed.



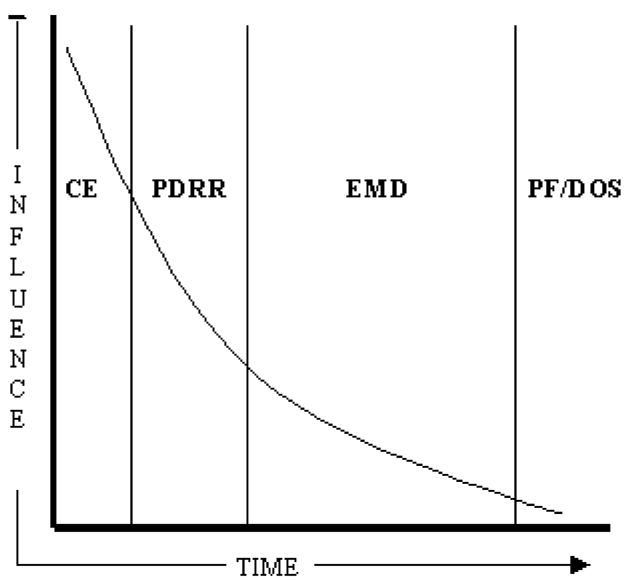
Detailed Design

The detailed design of the system and all of its components, processes, and materials will be completed during the latter part of Engineering and Manufacturing Development or early in Production. Design solutions are documented using item detail, process, and material specifications, associated drawings, and other technical documentation.



Life-Cycle Costs (LCC)

The earlier a decision is made in the life cycle of a system, the more influence it can have on the overall LCC of the system.



Remember, an effective Systems Engineering Process used throughout the development cycle will help meet LCC objectives and enhance cost stability throughout the system's life.

Concept Exploration (CE) and LCC

Choosing a missile versus an aircraft in the Concept Exploration phase can substantially affect the costs throughout the entire life cycle. Once a particular system is selected, a large portion of the total LCC is established.

Program Definition and Risk Reduction (PDRR) and LCC

Key decisions made during this phase cause subsequent decisions to have a decreasing effect on LCC. Some of these include:

- Support concepts.
- Technologies and materials to be used in designing and manufacturing the system.
- Types of training.
- Personnel required to operate and maintain the system.

Engineering and Manufacturing Development (EMD) and LCC

Although often the longest phase in the development cycle, EMD should have only minor influence on the LCC if effective cost/performance tradeoffs were performed in the earlier phases.

Production, Fielding/Deployment and Operational Support (PF/DOS) and LCC

In the final life-cycle phase, there should be little or no impact on the LCC. Ideally, all risk should be known and managed. In practice, system improvements to correct performance or support shortfalls can have an effect on LCC.

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Good Design Characteristics

Characteristics of an Effective Design

It is tempting to define good design only in terms of system performance. While the ability of the system to accomplish its operational mission parameters is an important characteristic, a good design has other equally important attributes.

Effective Design Attributes

In addition to mission performance, an effective system design should exhibit the following attributes:

- The system must be designed to be cost-effectively supportable over its life cycle (e.g., reliable, maintainable).
- The system must be cost-effectively producible. This is an important design aspect as it affects both the materials used and the manufacturing processes.
- The system must be affordable. Cost is a design requirement that weighs equally with performance.
- Finally, a good design must be testable so that the user can verify that it is capable of

accomplishing its assigned mission(s).

Integration of Design Attributes

An integrated effort that uses the IPPD processes and IPTs ensures that:

- All characteristics of a good design are considered in the SEP.
- The major goals of the process are fulfilled to meet user requirement/needs.
- Design issues are addressed early avoiding increases in both acquisition and in the Life-Cycle Cost.
- Risks are identified and managed.

System Design and SEP goals

An effective system design supports the achievement of the following seven SEP Goals:

- **Cost Efficiency**

  The system design should allow the Government to acquire a system that meets performance requirements at a reasonable price. Also, the system design should allow for planned improvements without costing an exorbitant amount.

- **Fully Integrated Software**

  The system design should ensure that software works effectively with the rest of the system and other related systems.

- **Mission Performance**

  The system design should meet all of the user's requirements for accomplishing the operational mission.

- **Producibility**

  The system design should ensure producibility. Producibility is the relative ease of manufacturing an item or system. The characteristics and features of the design can govern whether available manufacturing techniques can be used. Using existing manufacturing techniques enables more economical fabrication, assembly, inspection, and testing.

- **Technology Transition**

  The system design should take full advantage of new technology developed by laboratories for other systems. Technology transition can reduce the cost of new technology development.

- **Supportability**

  The system design should ensure supportability. Supportability requires that the system design and planned logistics resources (including the logistic support elements) meet system availability and wartime utilization requirements.

- **Testability**

  The system design should ensure testability. Testability is the ability of the user to verify that the system is capable of accomplishing its assigned mission under realistic operational conditions.

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